The Far-Infrared Spectroscopy of the Troposphere Project --"FIRST"

Project Overview and Status

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and

The FIRST International Science Team

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University of Maryland Conference Center

FIRST International Science Team

"Who's on FIRST"

Marty Mlynczak (PI)	NASA Langley
Dave Johnson (TL)	NASA Langley
Charlie Hyde (PM)	NASA Langley
Stan Wellard (PM)	Utah State/SDL
Gail Bingham	Utah State/SDL
Ken Jucks	Smithsonian Astrophysical Observatory
Wes Traub	Smithsonian Astrophysical Observatory
Larry Gordley	G & A Software
Dave Kratz	NASA Langley
Ping Yang	Texas A & M University
Bill Smith	NASA Langley
Lou Smith	Virginia Tech
Paul Stackhouse	NASA Langley
Chris Mertens	NASA Langley
Bob Ellingson	Florida State University
Rolando Garcia	NCAR ACD
Bill Collins	NCAR CGD
Brian Soden	GFDL
John Harries	Imperial College, London
Rolando Rizzi	U. Bologna, Italy

Outline

- Background of Earth Radiation Budget Measurements
  - Compelling science in the far-IR
- FIRST – Technology Overview
  - FTS
  - Beamsplitters
  - Detectors
- FIRST – Summary and Future beyond IIP

A Brief History of Earth Radiation Budget Measurements

ERB measurements from space first proposed by V. Suomi in late 1950's

First quantitative measurement of Earth System from space was ERB in late 1950's, early 1960's

Measurement is of 2 "classic" energy flows:

1. Total Radiation = Emitted Thermal + Reflected Solar
2. Reflected Solar Radiation

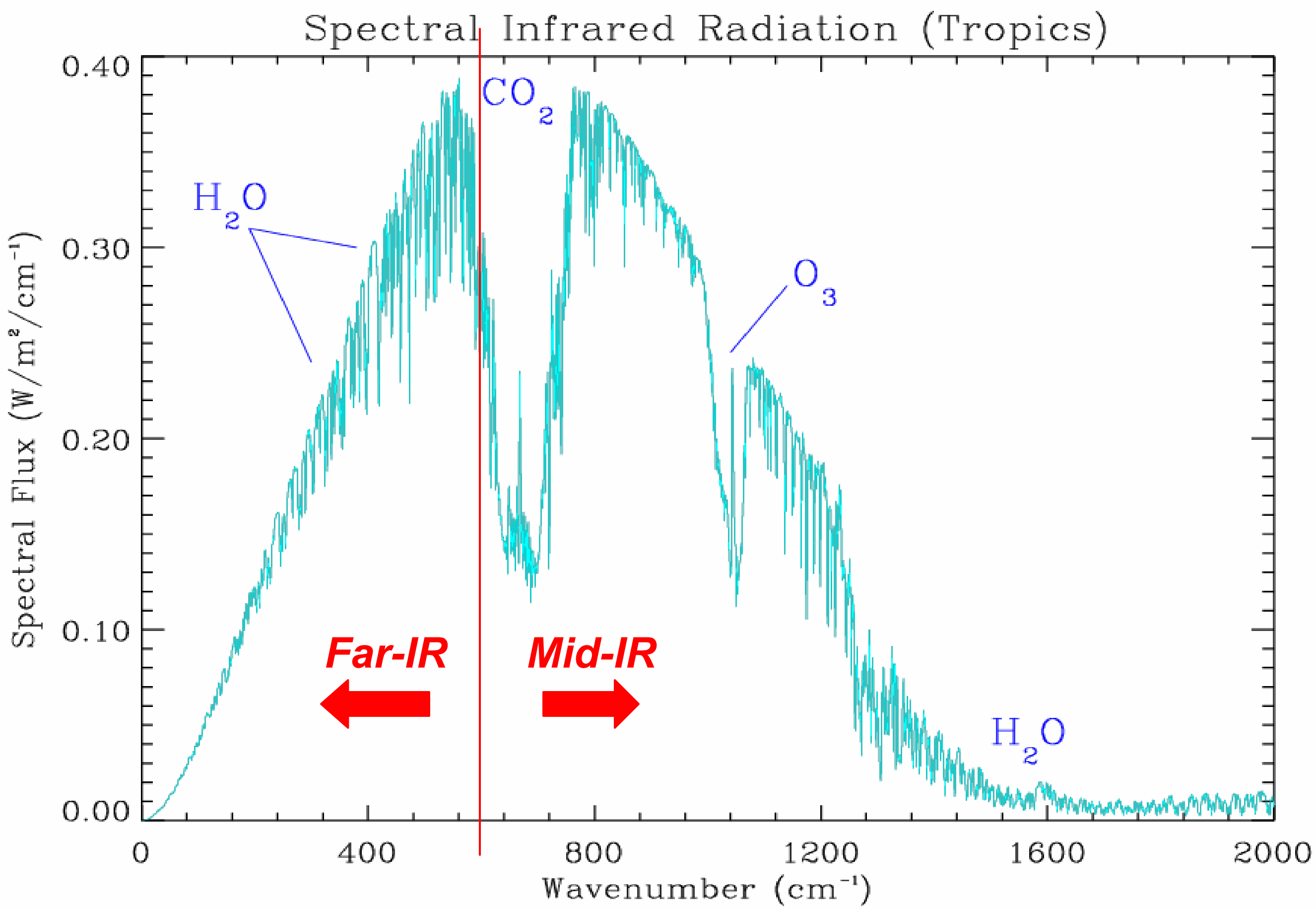
Emitted thermal radiation obtained by subtraction of classic energy flows

In the past 40 years these measurements have been refined in terms of:

1. Improved spatial resolution
2. Improved calibration
3. Improved angular sampling

Two critical dimensions remain – temporal (GERB) and spectral (FIRST)

Far-Infrared Spectroscopy of the Troposphere



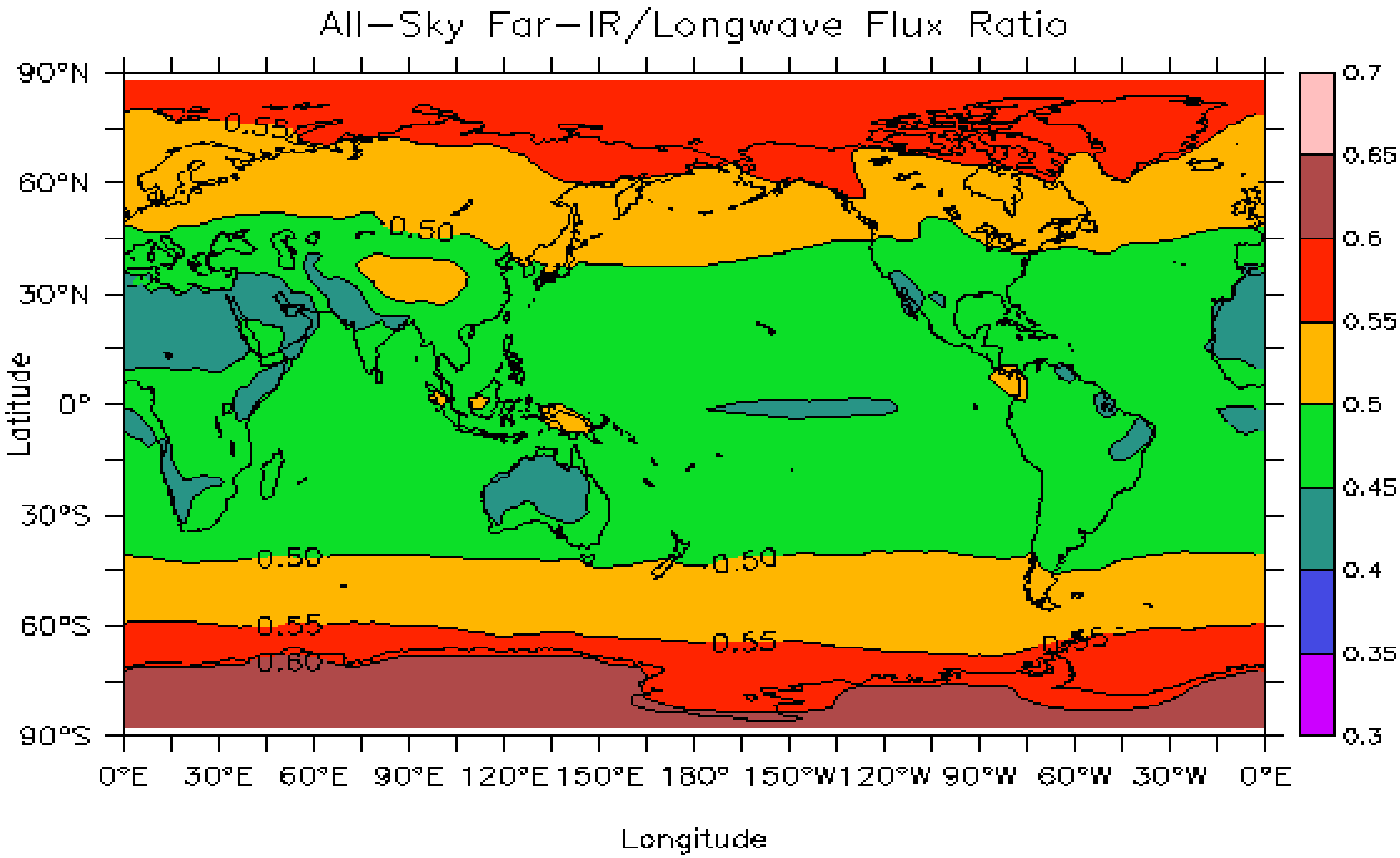
Far-Infrared Spectroscopy of the Troposphere

Compelling Science and Applications in the Far-Infrared

- Up to 50% of OLR (surface + atmosphere) is beyond 15.4 μm
- Between 50% and 75% of the atmosphere OLR is beyond 15.4 μm
- Basic greenhouse effect (~50%) occurs in the far-IR
- Clear sky cooling of the free troposphere occurs in the far-IR
- Radiative feedback with H_2O and greenhouse gas increase is in the far-IR
- Cirrus radiative forcing has a major component in the far-IR
- Longwave cloud forcing in tropical deep convection occurs in the far-IR
- Improved water vapor sensing is possible by combining the far-IR and standard mid-IR emission measurements

Direct Observation of Key Atmospheric Thermodynamics

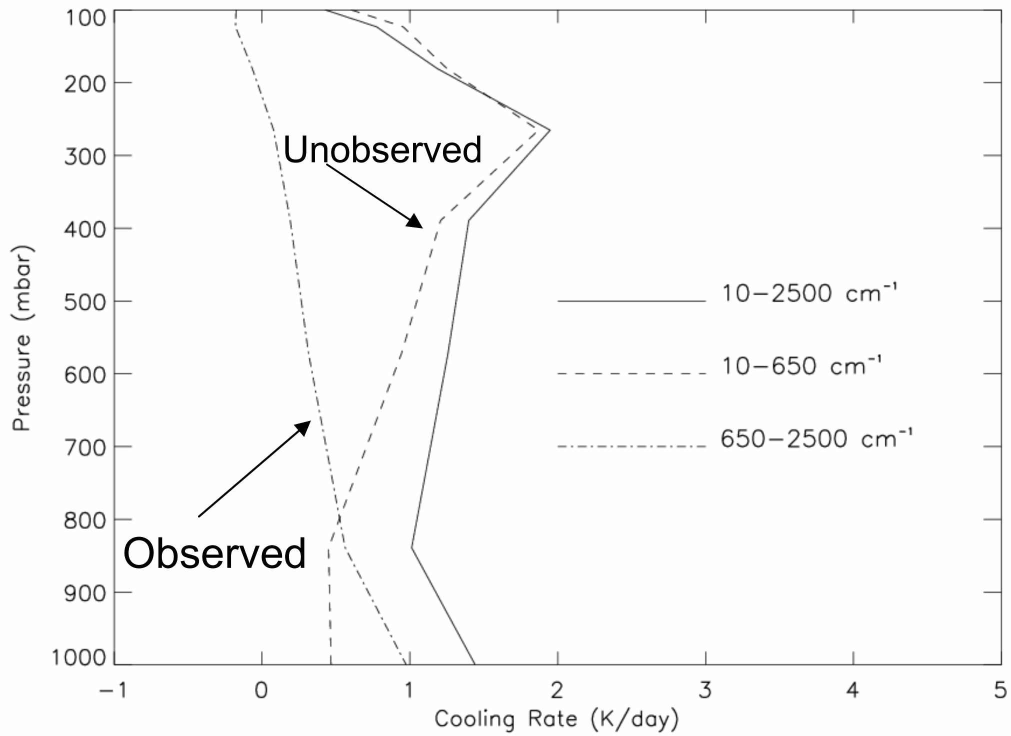
Far-Infrared Spectroscopy of the Troposphere



Annual mean TOA fluxes for all sky conditions from the NCAR CAM

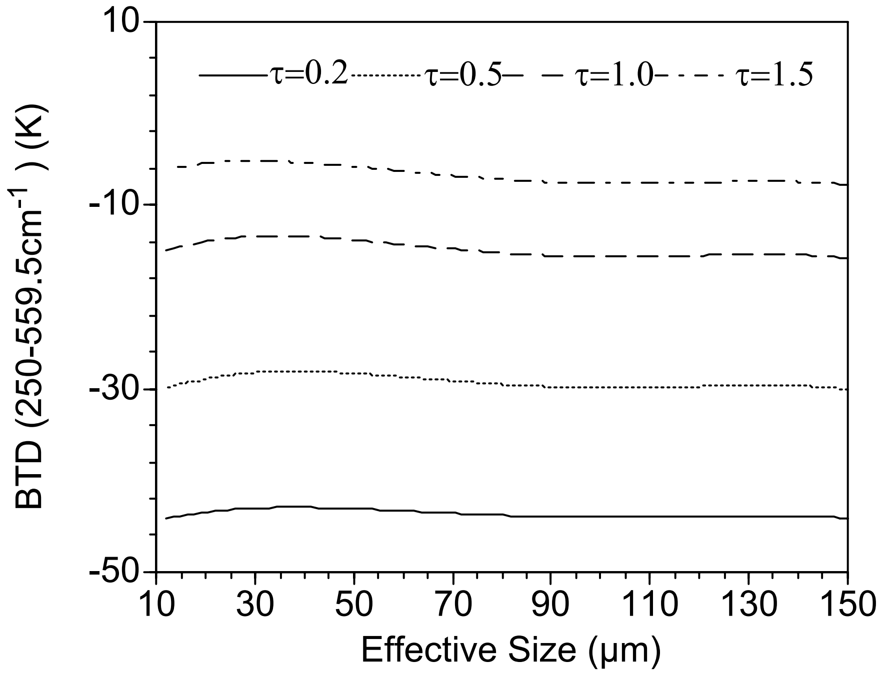
Reference: Collins and Mlynczak, Fall AGU, 2001

Far-Infrared Spectroscopy of the Troposphere



Spectrally Integrated Cooling – Mid-IR vs. Far-IR

FIRST – Sensitivity to Cirrus Clouds



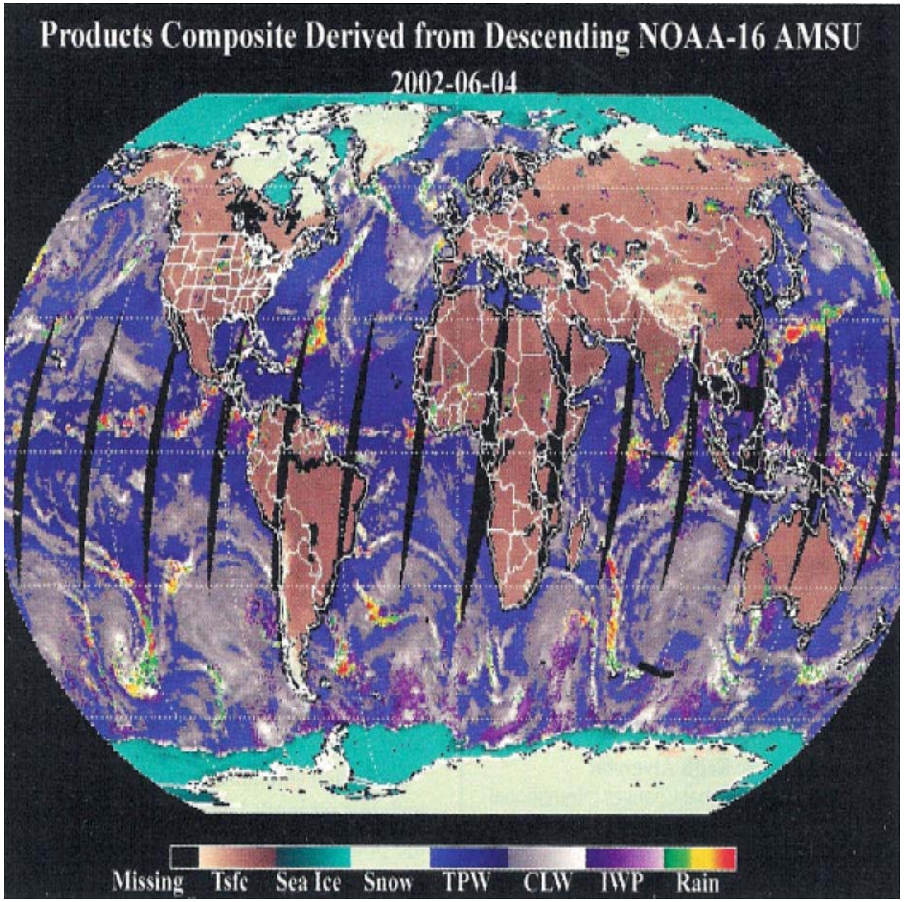
Brightness temperature difference between two channels ν_1=250.0 cm^{-1} and ν_2=559.5 cm^{-1} as a function of effective particle size for four cirrus optical thicknesses

FIRST spectra can be used to derive optical thickness of thin cirrus clouds (τ < 2). Reference: *Yang et al.*, JGR, 2003, in press.

Primary Roles and Responsibilities on FIRST

- NASA Langley
  - Science Lead, Technical Lead, Project Management
- Utah State University Space Dynamics Laboratory
  - Interferometer, payload integration, sensor management
- Smithsonian Astrophysical Observatory
  - Beamsplitter Development
- G and A Technical Software
  - Calibration Plan
- Science Team
  - Code comparisons, science applications, science justification

FIRST Instrument Requirements



(From EOS 83:29, 2002 – NOAA Satellite-derived Hydrologic Products)

- Global Coverage
- 10 – 100 μm (1000 – 100 cm^{-1})
- 0.6 cm^{-1} spectral resolution (UA)
- NEΔT = 0.2 K (10 - 60 μm)
- NEΔT = 0.5 K (60 - 100 μm)
- LEO satellite compatible
- ERB calibration capability and stability

Goals

- NEΔT = 0.2 K (10 - 100 μm)
- IFOV sampling $\leq$10 km

Far-Infrared Spectroscopy of the Troposphere

FIRST goal is to develop technology to make spectral sensing of the entire infrared spectrum routine using an imaging Michelson Interferometer

Key technology elements of FIRST:

- High Throughput Michelson Fourier Transform Spectrometer (FTS)
  10 - 100 μm, 0.6 cm^{-1} resolution
- Broad bandpass beamsplitter
  Germanium on polyproylene
- Thermal design to incorporate liquid-helium cooled detectors coupled to
  Winston cones and an integrating cavity for each detector

FIRST will demonstrate these technologies on a high-altitude balloon in 9/2004.

FIRST Technology Overview

Technical Challenge: High Throughput Interferometer

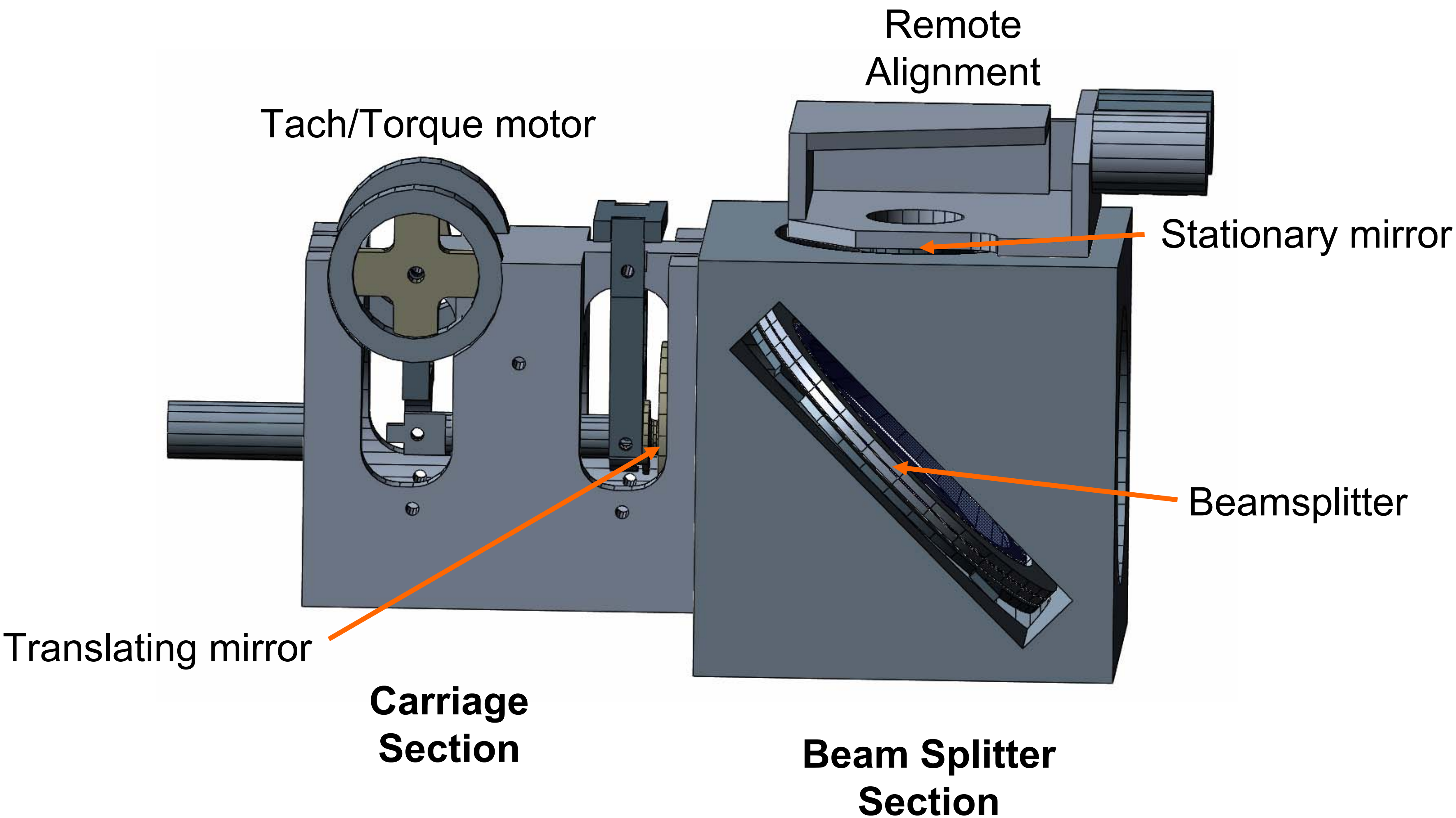
- We require a Fourier Transform Spectrometer (FTS) with very high throughput to illuminate a focal plane array of Winston cones and achieve the desired sensitivity, field-of-view, and global coverage

Solution:

- We will use the proven compact plane-mirror Michelson design developed by the USU/SDL for the (GIFTS) for Langley under NMP
- FIRST throughput will be double that of GIFTS
- Required to uniformly illuminate focal plane of 100 detectors in an area of 1.5 x 1.5 in
- The required increase in throughput will be achieved by doubling the mirror area

TRL 3 to TRL 5

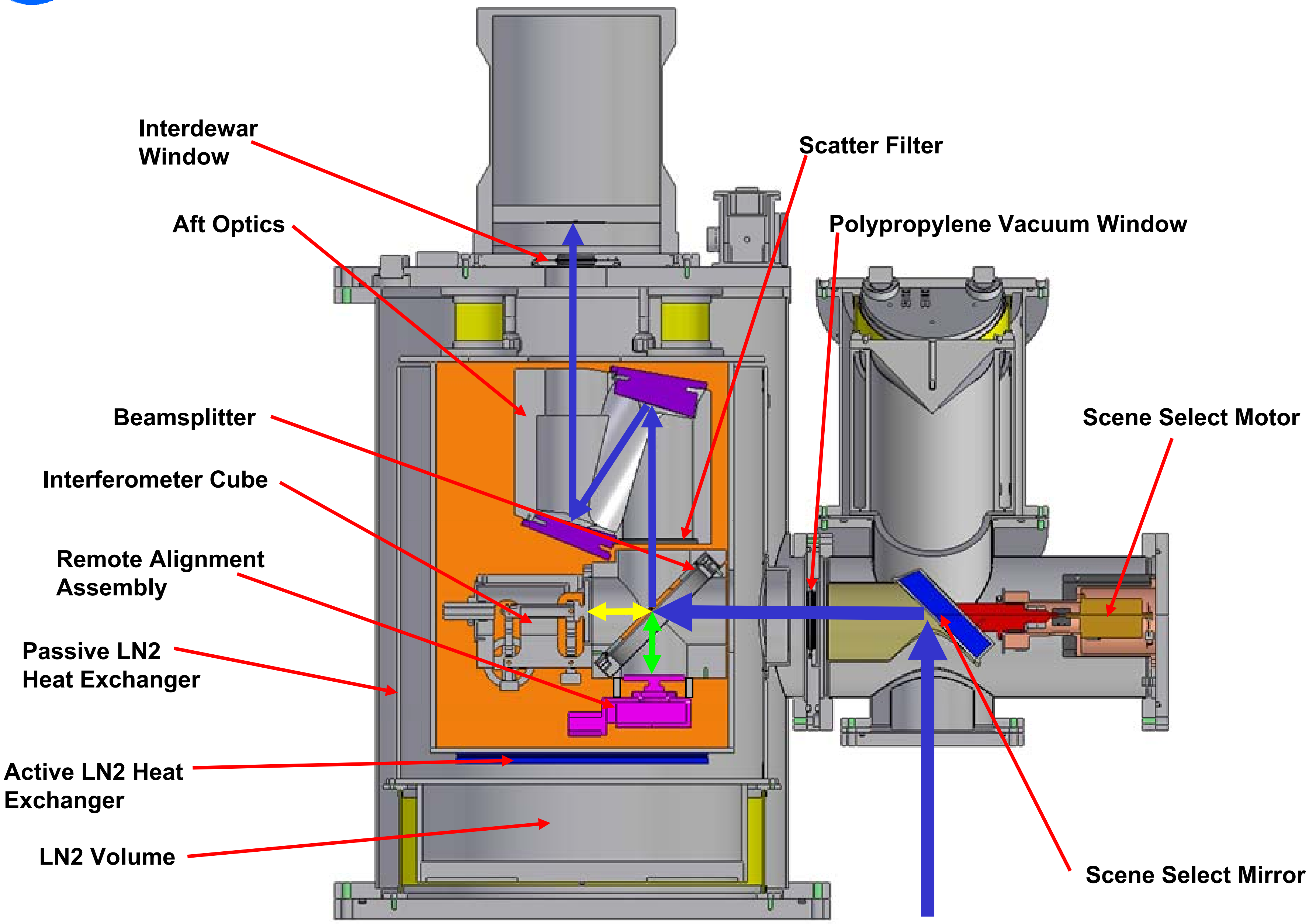
FIRST Interferometer Block Diagram



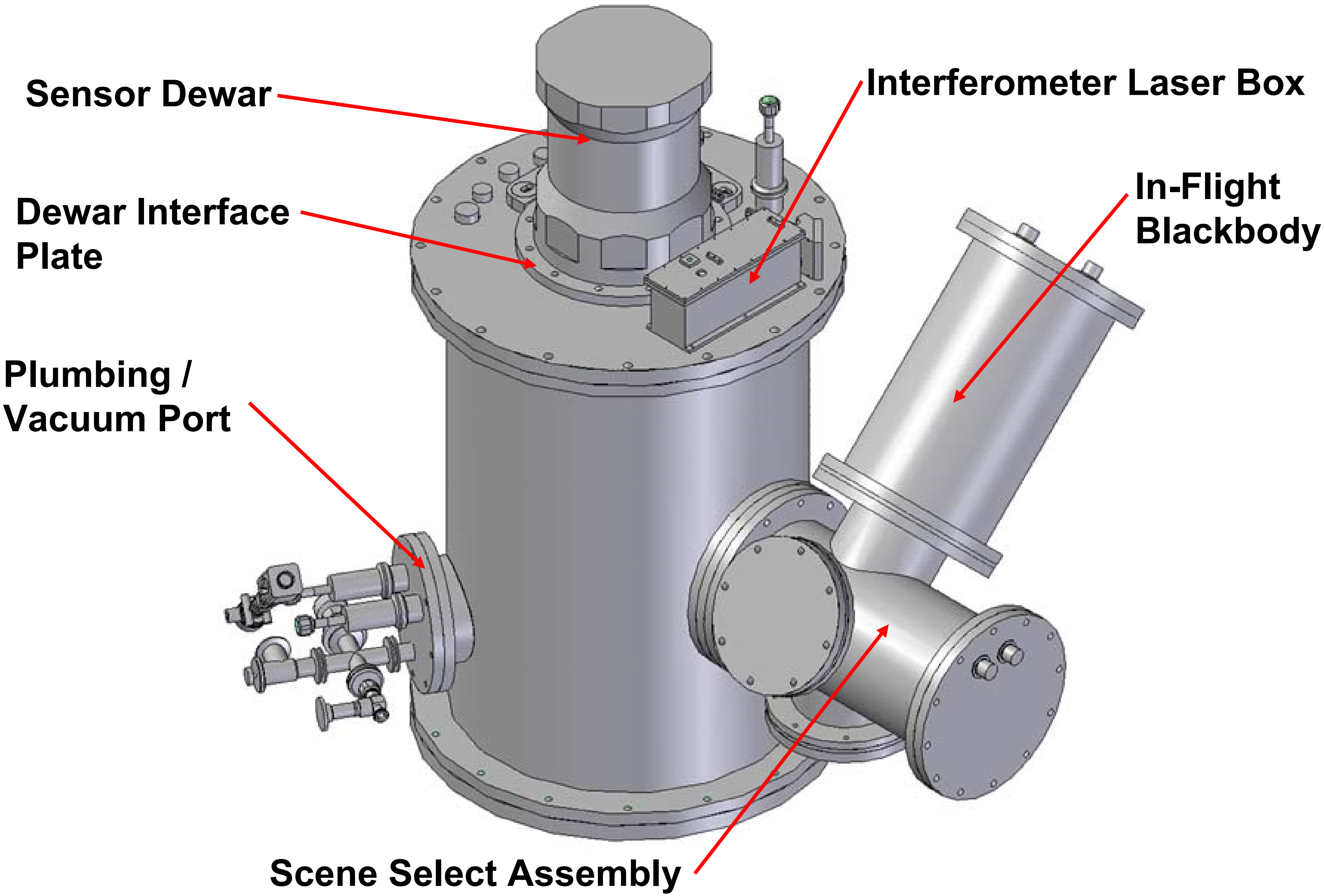
FIRST Optical System Design Features

- Fast, compact, all reflective optical system
- Array of F/6.5 Winston cones for increased radiometric efficiency
- Operates in the 10 μ < lambda < 100 μ wavelength range
- There is negligible vignetting in this design
- The spot size of this design is significantly smaller than the Winston cone entrance aperture
- The focal plane is normal to the incident beam
- Tolerance analysis shows the system is very insensitive to small variations in mirror positions
- The focus is insensitive to shifts of several millimeters

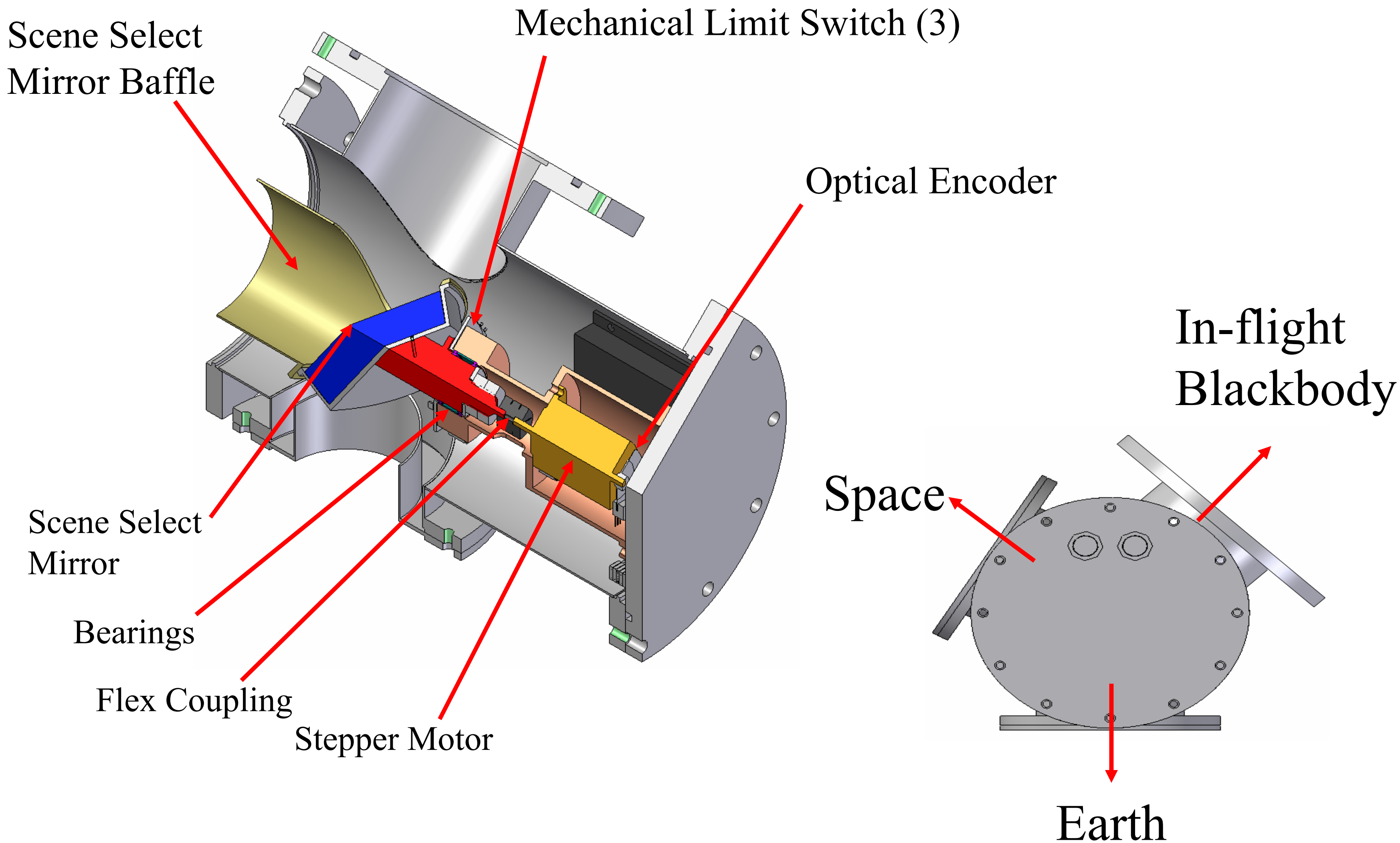
FIRST Balloon Payload System



FIRST Balloon Payload System

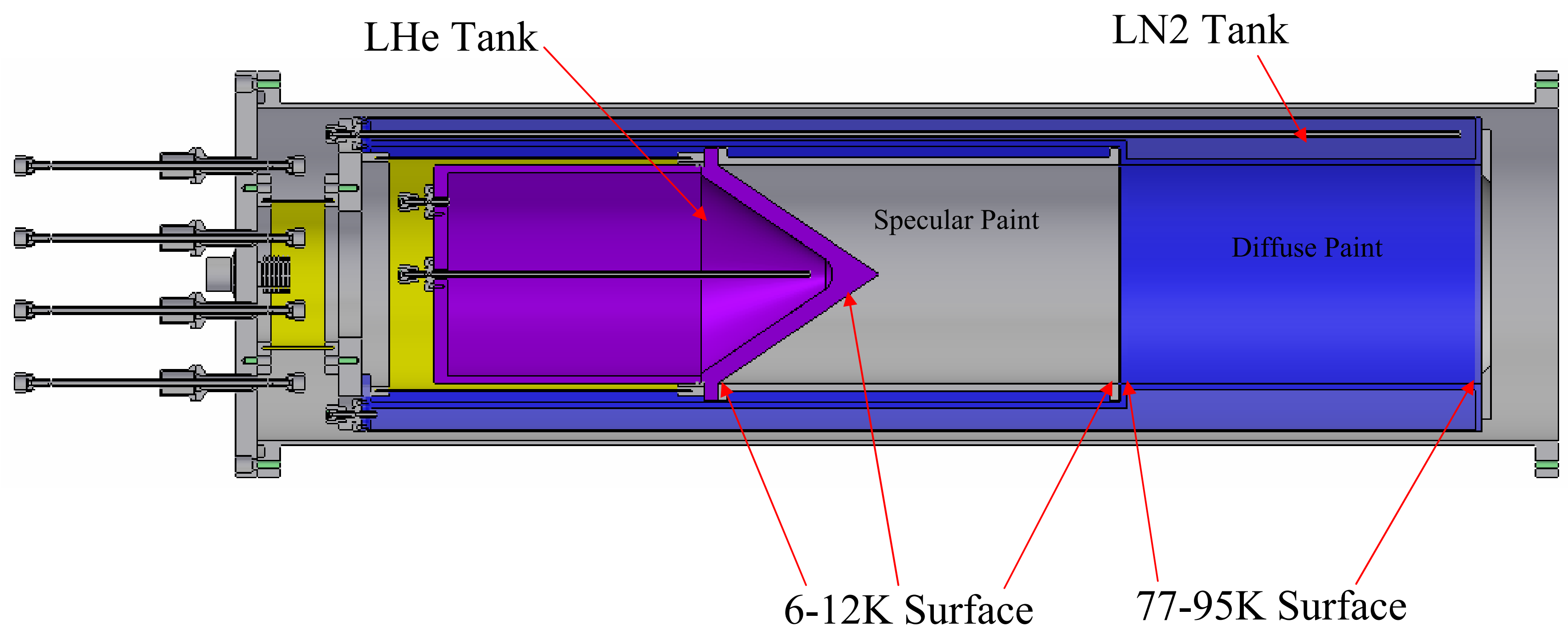


FIRST Scene Select Assembly

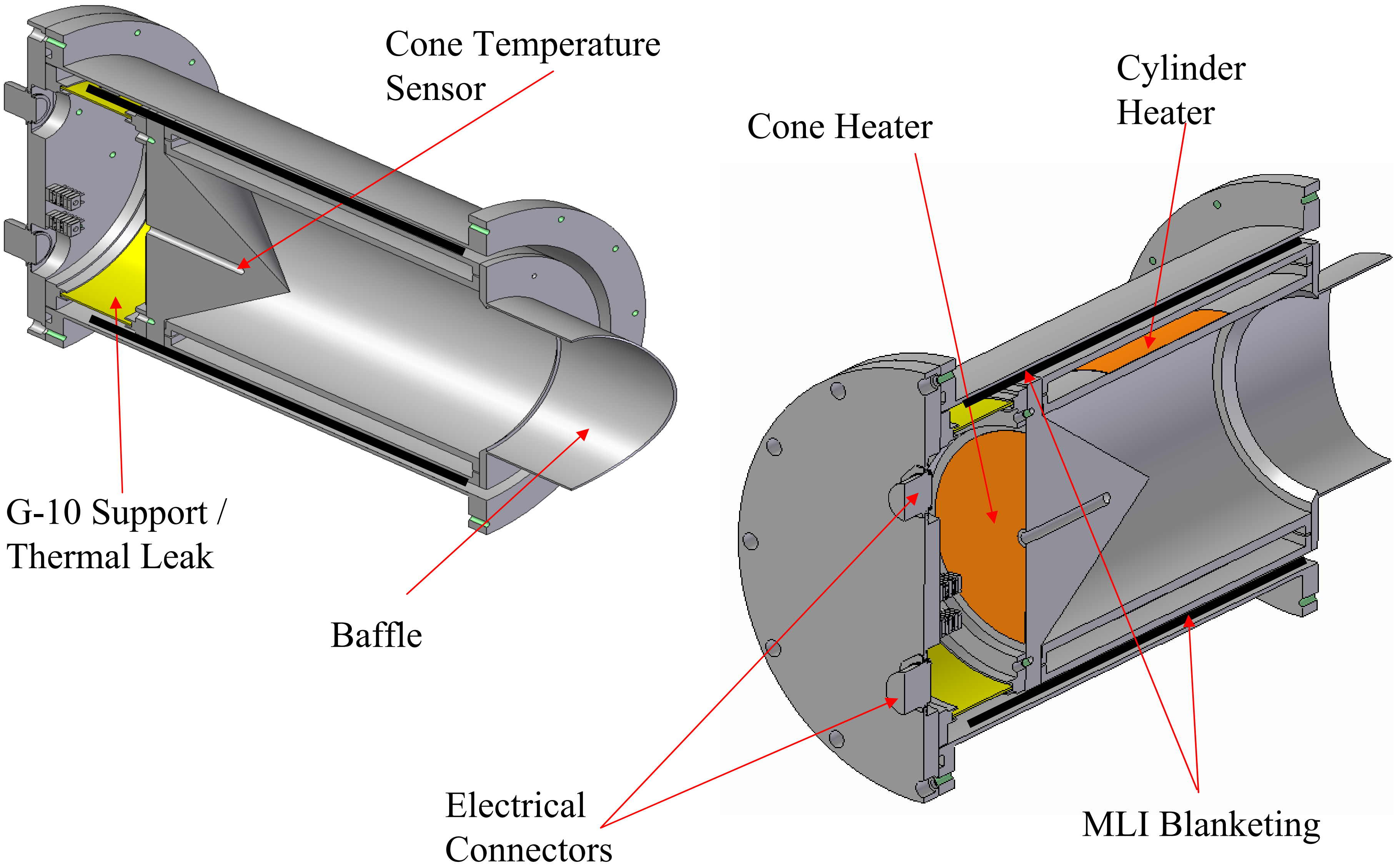


FIRST Space View Simulator

- Provide a cold source for calibration (<25K)
- Capable of operating while attached to any of the three scene select positions
- 2 hour hold time
- Silicon diode temperature detectors

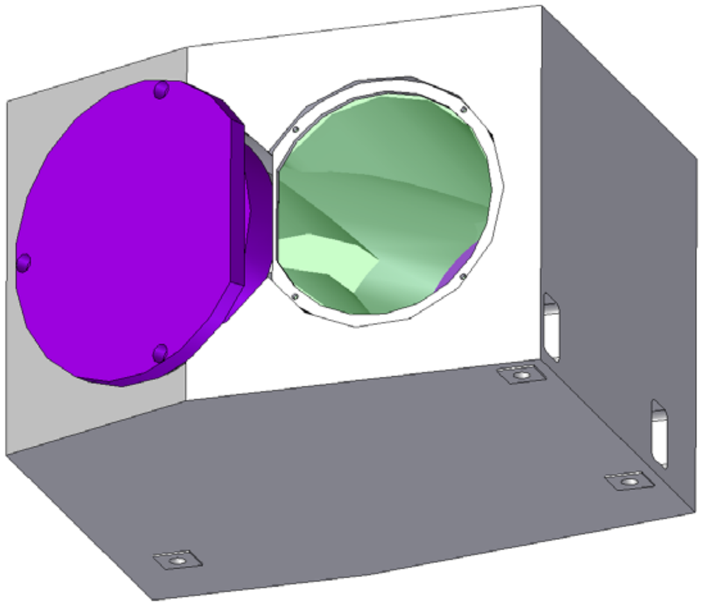


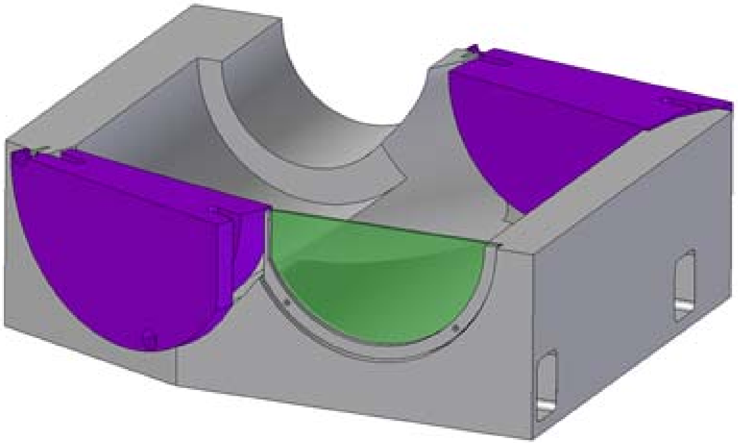
FIRST 300K In-Flight Blackbody



FIRST Optical Box – Aft Optics

- All 6061-T6 Aluminum
- Diamond Turned:
  - Optical surfaces
  - Mounting pads for mirrors to Aft Optical Bench
  - Mounting pads for Aft Optical Bench to Optical Box
- Optical vendor to heat treat mirrors and bench, then perform diamond turning
- Components machined to tolerances that allow final assembly at SDL



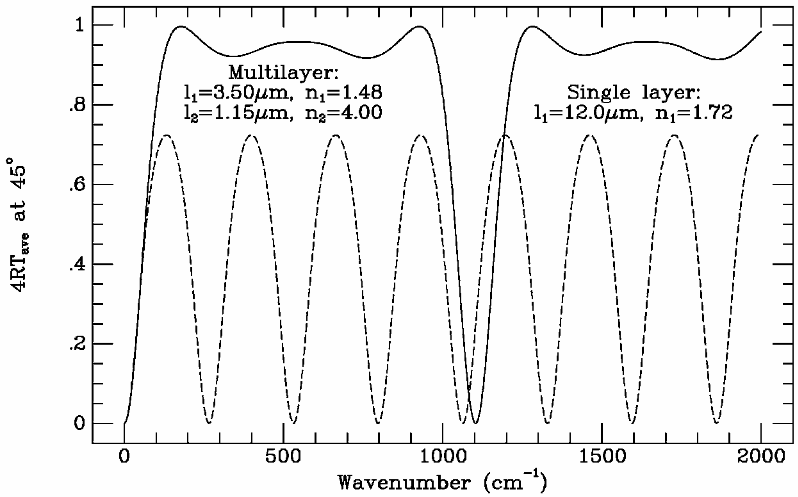


FIRST Technology Overview

***Technical Challenge*: Beamsplitters**

We require the best possible performance from 10 – 100 μm (100 – 1000 cm^{-1}).

Individual conventional beamsplitters cover only parts of this range with high efficiency

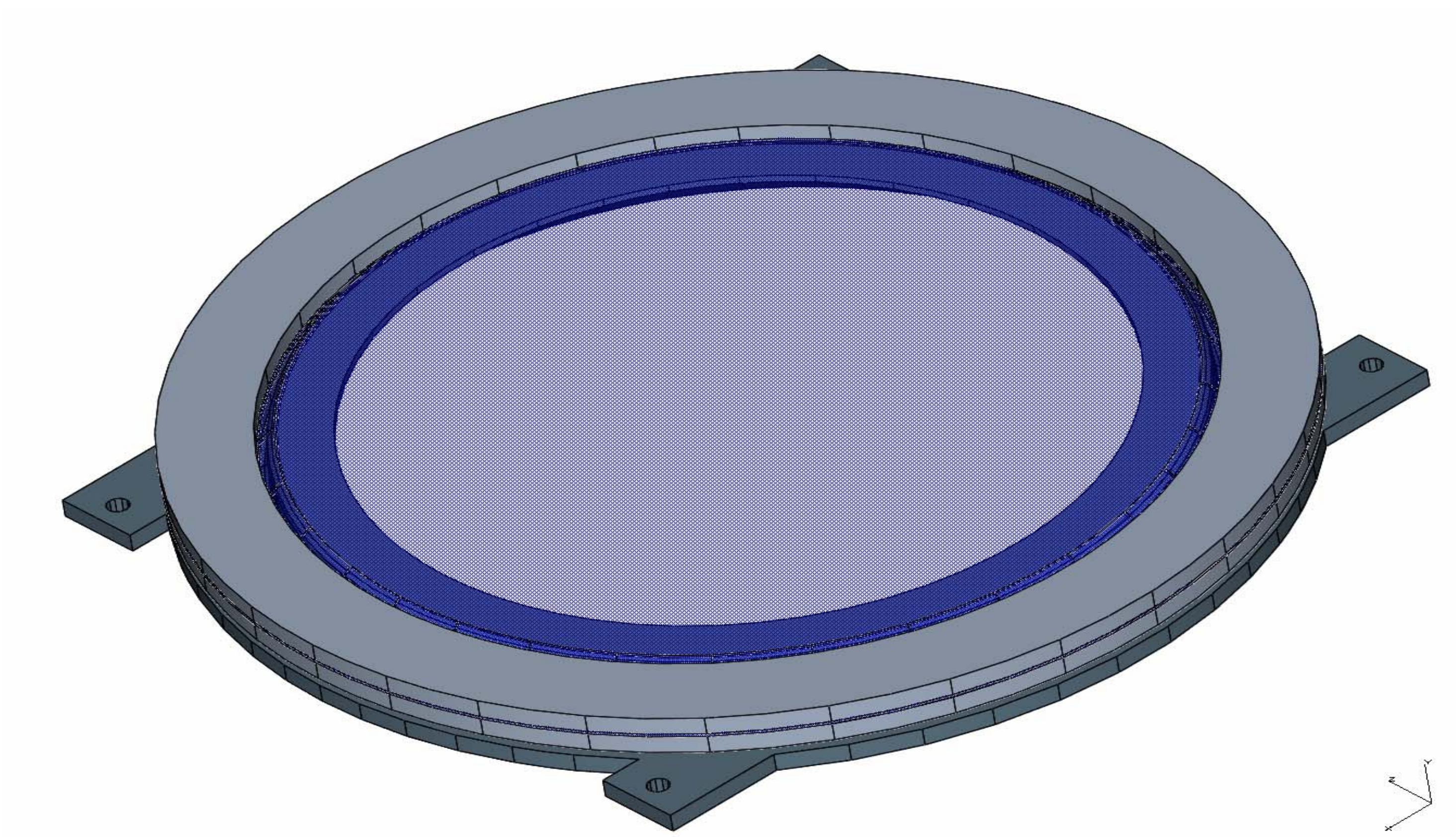


***Solution*:**

Bilayer pellicle beamsplitters being developed at the Smithsonian Astrophysical Observatory (SAO) can cover the desired infrared band with better than 90% efficiency – Germanium on polypropylene

TRL Level 4 to TRL Level 5

Far-Infrared Spectroscopy of the Troposphere

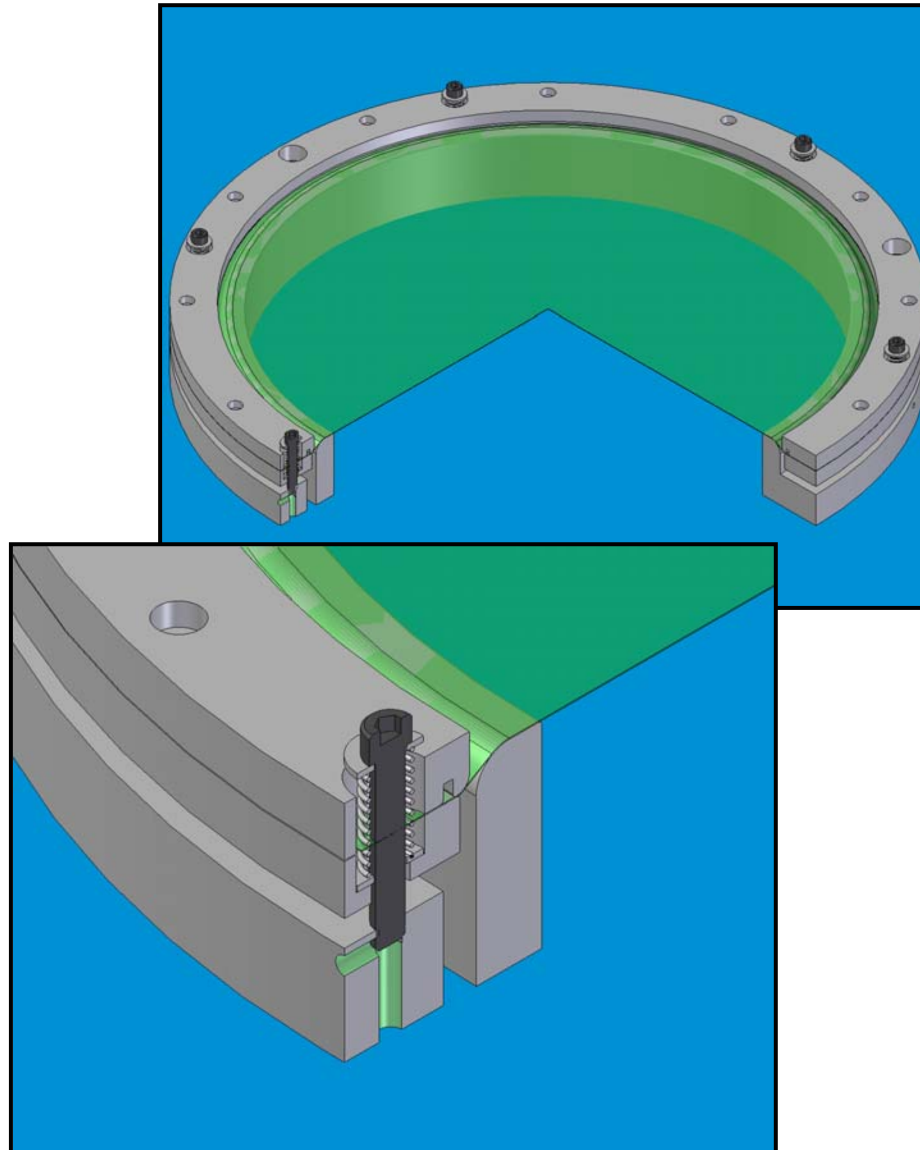


Beam Splitter Ring

FIRST Optical Box – Beamsplitter

- Beamsplitter Assembly:
  - SAO provides pellicle assembly
  - SDL completes assembly

- Beamsplitter Base Ring:
  - 6061-T6 aluminum
  - Heat treated
  - Diamond turned
  - 6 springs:
    - capable of applying 5# of tension



FIRST Technology Overview

***Technical Challenge*: Far-Infrared Detector and Winston Cone Array**

We require IR detectors that can achieve high sensitivity over kilohertz bandwidths and that can provide long lifetime and low power usage on orbit

Solution:

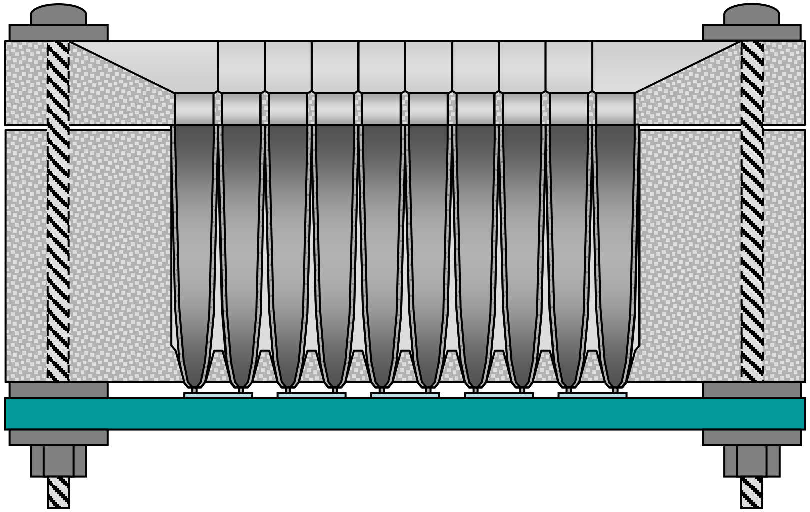
FIRST Team has evaluating a variety of technologies-

- Antenna-coupled bolometers or pyroelectric detectors – passive cooling
- Standard pyroelectric detectors – passive cooling
- Cooled photoconductors -
- High T_c bolometers

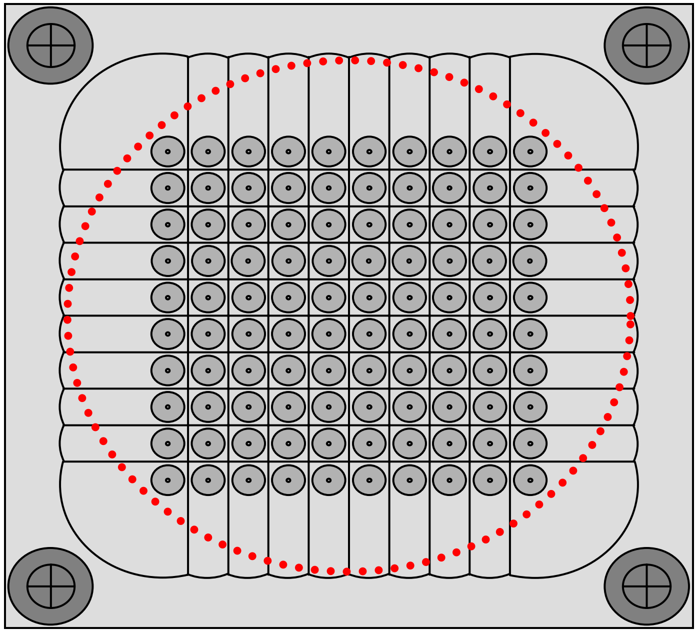
FIRST has selected LHe cooled photoconductors, coupled to Winstion cones to achieve required high sensitivity, bandwidth, and to ease the challenge of calibration

TRL 3 to 5

Far-Infrared Spectroscopy of the Troposphere

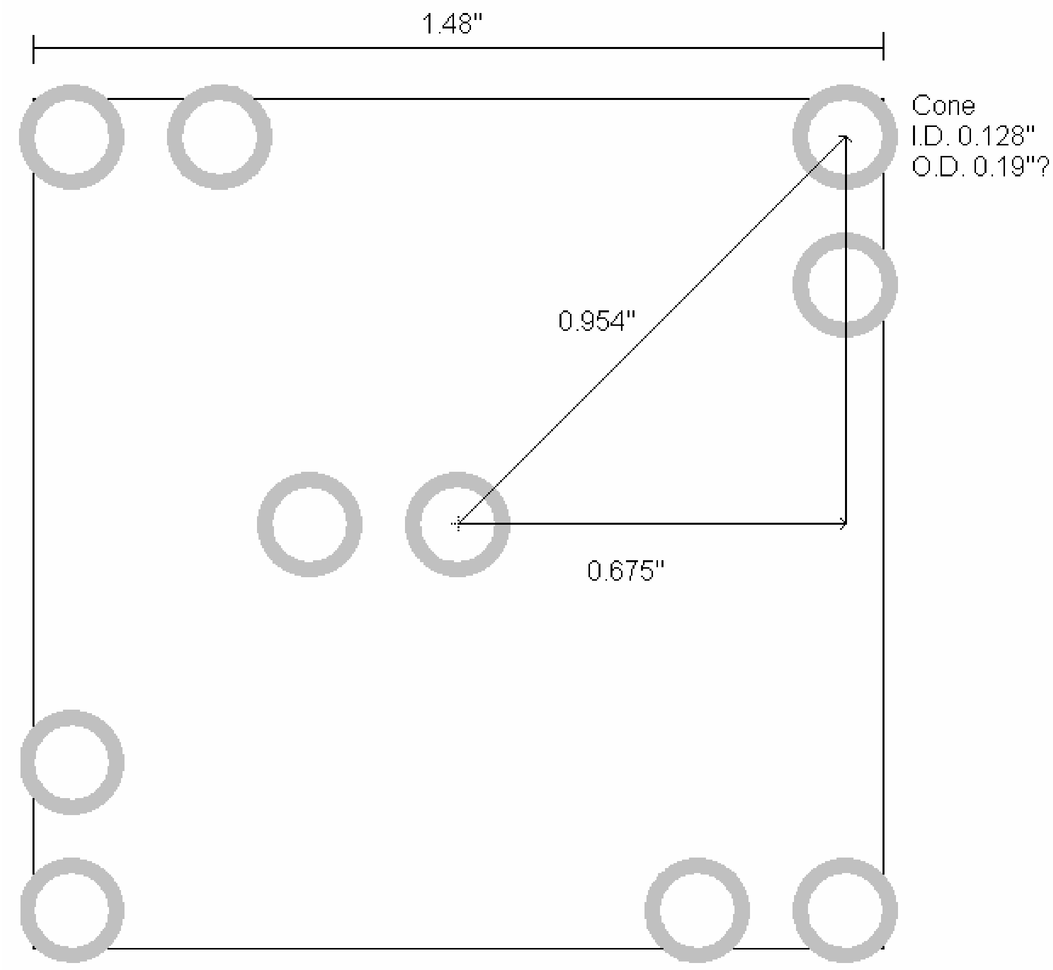


FIRST Focal Plane, Side View



FIRST Focal Plane
(square packed, top view)

FIRST Winston Cone Array



FIRST – Summary and Future

FIRST is developing technologies in FTS, beamsplitter, and focal planes to allow measurement of the previously unexplored Far-Infrared spectral region

Extremely compelling science in Far-Infrared not addressed due to previous technology limitations

FIRST Critical Design Review successfully completed in 5/2003

FIRST on schedule to flight demonstrate on a balloon platform in 9/2004

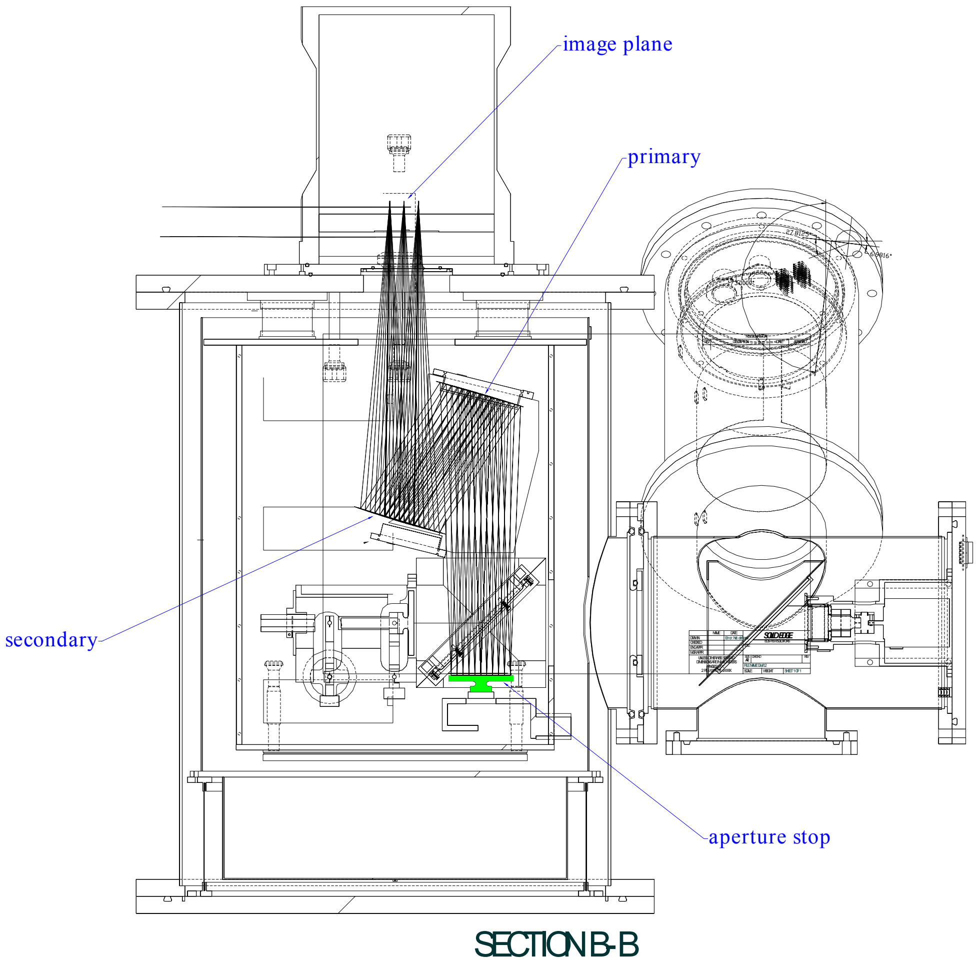
FIRST has potential contributions to AURA validation in area of:

- Temperature and water vapor profiles
- Cirrus optical depth measurements
- Basic radiation/greenhouse forcing in far-IR

FIRST Team working with LaRC, NASA, Int'l partners to find/develop mission for spaceflight of far-IR technology

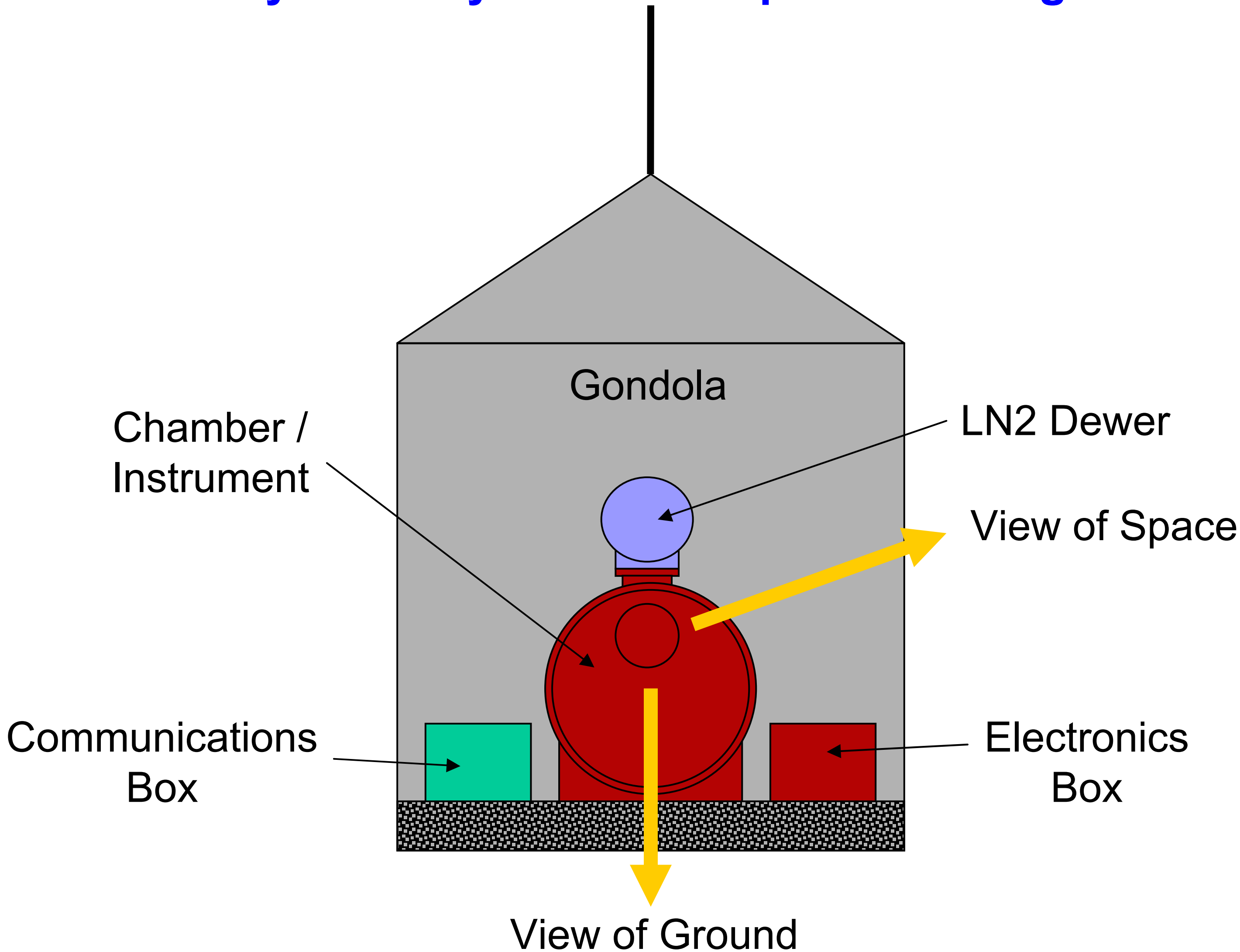
Backup Material

Telescope, mounted in dewar



Far-Infrared Spectroscopy of the Troposphere

System Layout – Conceptual Drawing



Far-Infrared Spectroscopy of the Troposphere

The portion of the infrared spectrum important for characterizing the energy balance of the Earth and atmosphere lies *between 4 and 100 μm*

Space-based measurements of the Earth's emission fall into 2 classes

1. Earth radiation budget, e.g., CERES, ERBE, GERB, SCARAB
   These measure the entire infrared little or no spectral distinction

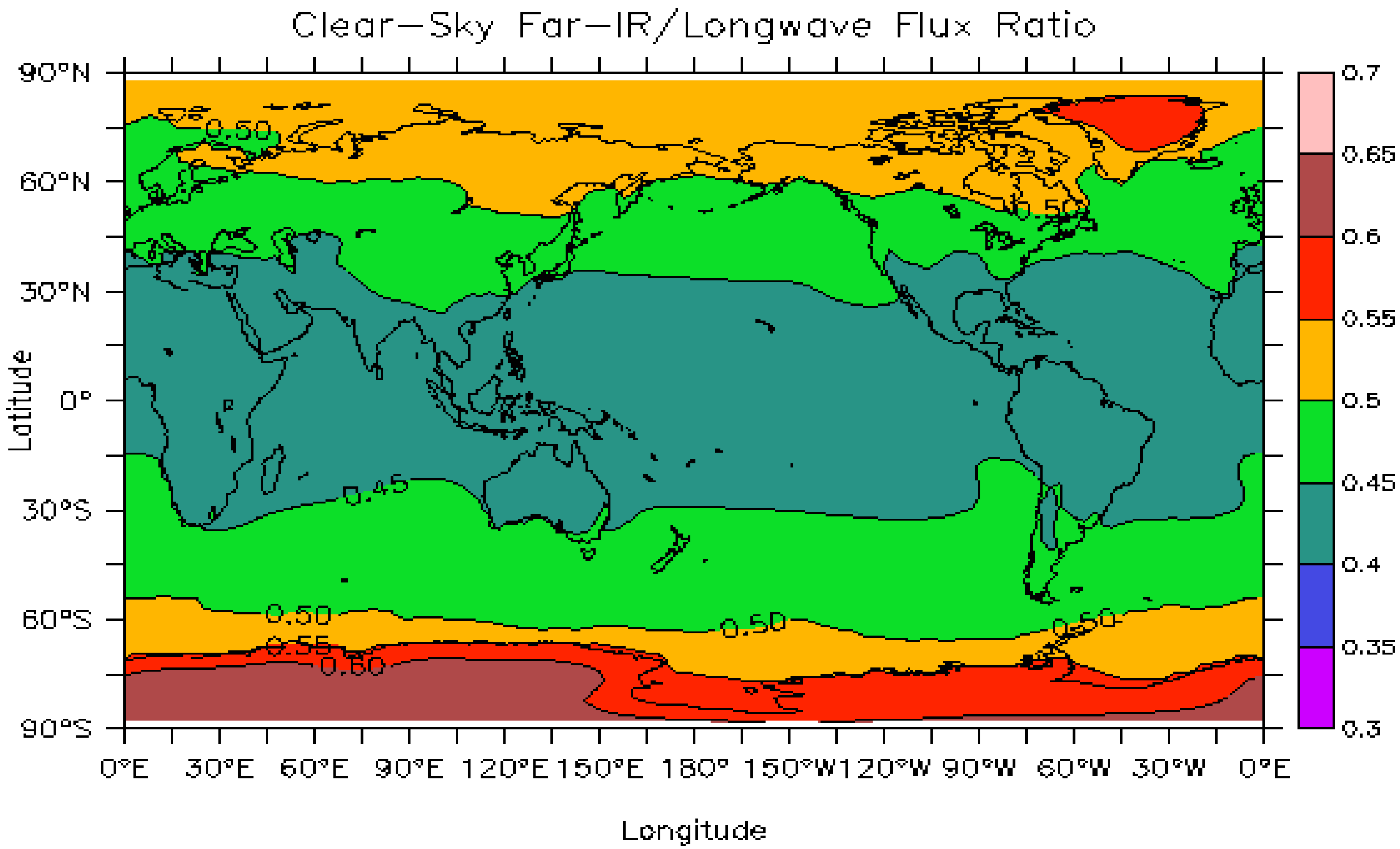
2. Spectrally resolved sensors, e.g., AIRS, MODIS, CrIS
   These measure part of the infrared, often not contiguously

We define the Far-IR as the part of the spectrum *longer than 15.4 μm*

All NASA and NPOESS *spectral* sensors presently selected or planned for spaceflight have *no sensing capability beyond 15.4 μm*

This situation primarily reflects current technology limitations and not scientific necessity - compelling reasons exist to measure the Far-IR

Far-Infrared Spectroscopy of the Troposphere

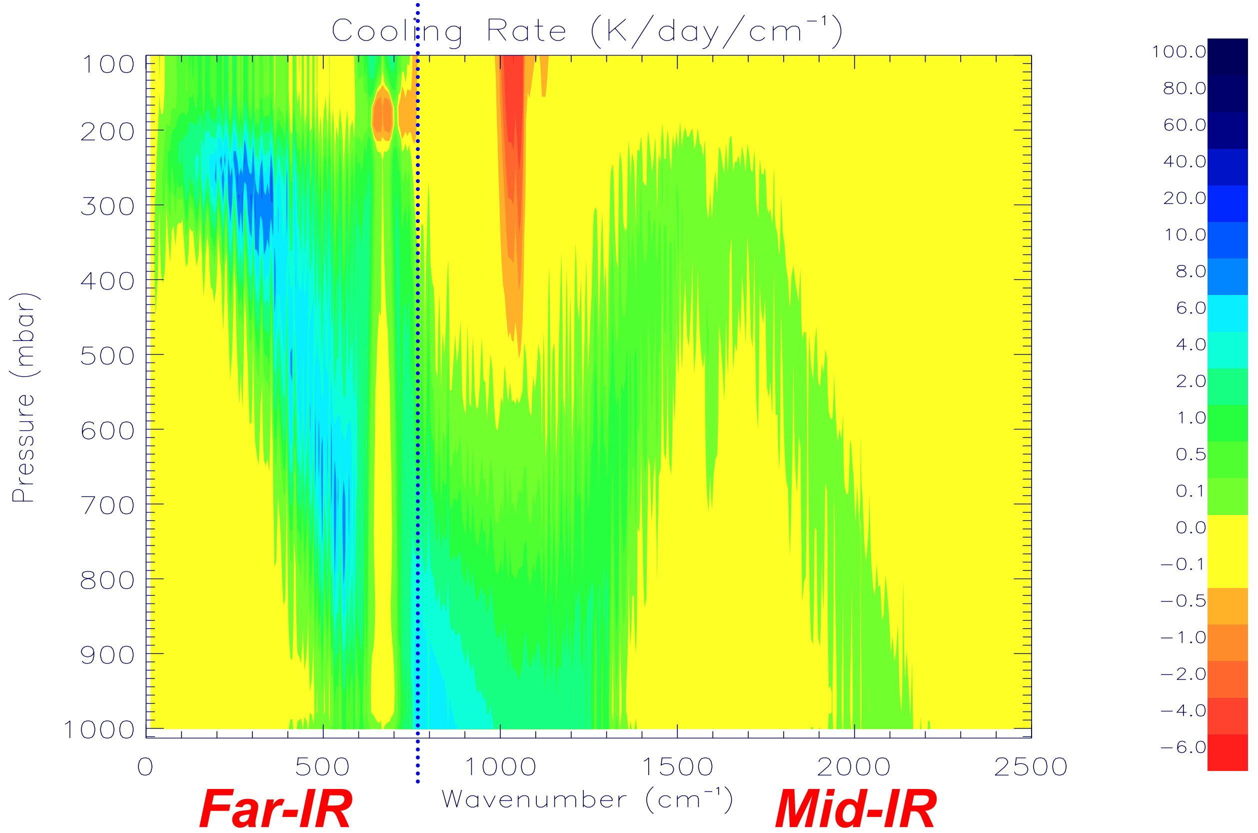


Annual mean TOA fluxes for clear-sky conditions from the NCAR CAM.

Reference: Collins and Mlynczak, Fall AGU, 2001

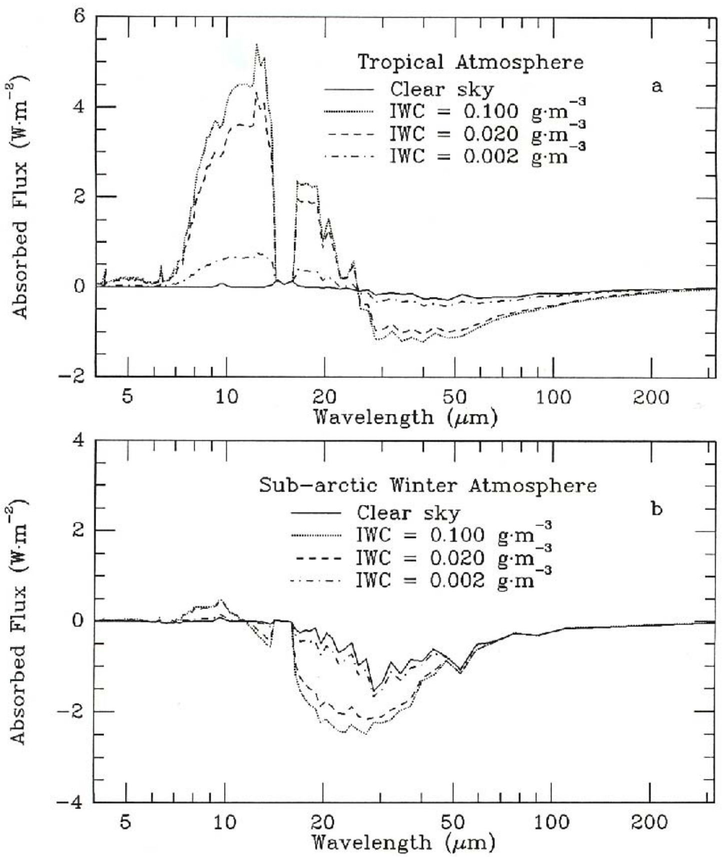
Far-Infrared Spectroscopy of the Troposphere

Clear-Sky Spectral Cooling Rate



Far-Infrared Spectroscopy of the Troposphere

Spectral Effects of Cirrus on Atmospheric Radiative Heating



<u>Tropical Atmosphere</u>

Mainly mid-IR radiative heating in cirrus

Weak far-IR cooling

Net effect of cirrus is local heating

<u>Sub-Arctic Winter Atmosphere</u>

Mainly far-IR cooling in cirrus

Weak mid-IR heating

Net effect of cirrus is local cooling

FIRST Optical System Design Features

- Fast, compact, all reflective optical system
- Array of F/6.5 Winston cones for increased radiometric efficiency
- Focal Plane Array (FPA) follows Winston Cones
- Operates in the 10 µ < lambda < 100 µ wavelength range
- The aperture stop diameter = 2.76 in (70 mm.), and is located at the fixed mirror of the FTIR
- The EFL is determined from $F\# = EFL/d_{EP}$, EFL = 17.9 in.
- This design form is known as a “Schiefspiegler” in the literature.
- It was first used for astronomical applications in the 1950’s, by Anton Kutter in Germany. The term “schiefspiegler”, stands for “oblique reflector”.
- System was modeled both in Zemax and CodeV.
- Both optical design codes agree in analysis results.

Optical Parameters for aft optics

- Aperture stop is 70 mm. in dia., coincides with FTIR fixed mirror
- Hyperboloidal primary, oblate ellipsoidal secondary
- Primary is used 8.0 in. off-axis, tilted 10 deg.
- Secondary is used 5.15 in. off-axis, tilted 12.3 deg wrt primary
- Aberration control is achieved by balancing tilts of pri. and sec.
- The image plane is parallel to the aperture stop, so the Winston cones need not be tilted wrt the plane of the fixed mirror.
- There is negligible vignetting in this design.

Conclusions

- The spot size of this design is significantly smaller than the Winston cone entrance aperture.
- Vignetting is negligible.
- The design is telecentric and the focal plane is normal to the incident beam.
- The FTS modulation efficiency for the outer cones using these optics is 90.1% compared to the theoretical maximum of 90.6%
- Tolerance analysis shows the system is very insensitive to small variations in mirror positions.
- The focus is insensitive to shifts of several millimeters.
- The design is diffraction limited in the center of the field at 10 microns and over the entire field for > 40 microns.